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ON GLIDE & CREEP OF THE SNOW COVER AMONG AVALANCHE DEFENSES

By H. Frutiger and J. Kuster

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Translated by E. LaChapelle

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Introduction

Stimulated by experiments in snow and avalanche research at the Weissfluhjoch (6), observations on the creep and glide of the snow cover in the avalanche defenses "Schilt" at Stein, Toggenburg, have been made since the winter of 1946/47. Since 1960 further observations have followed in the defenses "Mattstock" at Amden (14), "Kuenihorn" at St. Antoenien, "Ruchli-Schrims" at Pfaefers, "Kneugrat" at Braunwald, and "Wisstannegg and Nollen" at Arth. After a 20-year observation period we deem it advisable to report some of the conclusions on the character and significance of this snow cover motion which so often has disasterous effects on construction and afforestation. The winters of 1965/66 and 1966/67 have demonstrated these effects with especial clearness. The winter of 1965/66 was an outstanding "glide winter".

In the community of Conthey (Wallis) the gliding snow cover tore up about 3 hectares (7.5 acres) of forest and carried it down toward Planpra. On the Brienzergrat a 100-meter length of track on the Brienz-Rothorn Railway was destroyed along with the retention wall and carried 30 m toward the valley. In the supporting structures on the Kuenihorn at St. Antoenien-Castels, snow bridges and their foundations were pushed over and broken apart. The structures next to the ridge crest were unable to support a section of cornice involved in the glide motion and the descending snow mass destroyed 144 running meters of the defense. The damage amounted to about 100,000 Swiss francs. In addition, gliding snow sheared off the construction access road for

a length of 140 meters and tipped the roadbed down over the retention wall. The snow nets above the supporting structures and reforestation "Stotzigberg" at Pfaefers were almost all damaged and in large part destroyed.

Noteworthy glide damage also occurred in the winter of 1966/67. Of some 430 running meters of wooden snow rakes in the supporting structures "Blaisa" at Schiers, a good half was destroyed. These examples are only few among many.

Among earlier years the winter of 1952/53 is known as a glide winter. At that time barns were pushed over on Aussersulwald at Isenfluh (Bern) and in the Klosterweide at Amden (St. Gallen). Several buildings had been damaged or destroyed around the communities of Valens and Vaeson at Pfaefers (St. Gallen) (9, 11).

The effects of snow cover glide and creep have long been known to foresters and mountain farmers. They have already been repeatedly described in the Swiss Journal for Forestry (2, 3, 4). Hess described the phenomenon in a special chapter in the "Experiences with Avalanche Defenses" (5). Numerous methods for combatting and minimizing glide and creep damage among afforestation and avalanche defense projects have been recommended and utilized. Best-known are the interruption of slopes by trenches or earth-and-wall terraces, and the planting of stakes. Unfortunately even these structures themselves can be destroyed by strong gliding. Quite possibly their effectiveness is not so great as has been generally assumed. For this reason we have set ourselves

the task of investigating the snow cover movements in several avalanche defenses of the fore-Alp region.

In addition to published works, an especially valuable basic source has been the Winter Reports on the defenses and afforestation project "Schilt"/Stein which has appeared annually since 1946. Observations at the other mentioned defenses are set forth in the Internal Reports of the Swiss Federal Institute for Snow and Avalanche Research. These would not have been possible without the substantial and praiseworthy assistance of the local forest organizations.

The Weather Conditions

As a rule, the snow cover glides over the ground at lower altitudes in the Swiss Alps. The amount of glide depends on surface conditions, slope angles, and slope exposures. In addition to the orographic conditions, the weather and snow cover accumulation play important roles. It is only when favorable weather conditions prevail that exceptional gliding occurs with heavy damage. If we analyze the weather for the three glide winters 1952/53, 1965/66 and 1966/67, we encounter several parallels.

The most outstanding criterion is heavy snowfalls early in the winter with a rapid accumulation of a deep snow cover. If the early snowfalls were preceded by a warm summer or fall, the gliding is increased. The weather summaries of the Central Meteorological Office (MZA) (1) for the three winters ran as follows. November 1952: The region

of the Alps showed in some localities more than three times the normal amount of precipitation. There were unusually large amounts for November, exceeded only two or three times in the past (records since 1864). December 1952: Precipitation quantities in the fore-Alps amounted to 160% to 180% of the long-term average. November 1965: Precipitation quantities generally 150-230% of normal; in middle Wallis and around Schaffhausen-Bodensee frequently 250-300%! (The 184 mm at Lohn (SH) was the second highest November since 1864.) December 1965: Precipitation quantities generally above normal, Mittelbuenden around 150%, middle Wallis 250-300%, a few places 350-400% (second highest December total in Leukerbad since 1884). November 1966: Precipitation quantities in the eastern half of the country mostly 150%, some over 180%, and in some northeast localities over 210%. December 1966: Precipitation quantities generally above normal, in most areas between 130% and 200%, in a few around 220%.

During 1952 the months of September and October were normal or cooler than normal. The months prior to the first snowfalls of October in 1965 and 1966 were distinguished by warm weather. We cite again the MZA reports. October 1965: Temperatures in the Alps unusually high, at Saentis close to the previous October maximum. October 1966: Generally above normal, on the alpine peaks 2-2.5°C, in western Switzerland and Wallis 3°C, in the northeast 3.5°C above the long-term average. In the north and east, generally the warmest October in the last 100 years.

The warm months of July and August in 1952 probably made up the slight deficit of September and October, so that even at that time the ground was warmer than normal when the first snows arrived.

In all three winters the first snows down to around 1200 meters elevation arrived between the end of October and mid-November - about a half to a whole month earlier than normal. Already by mid-December the snow cover at elevations 1400 to 1500 meters was 0.8 to 1.5 meter, in 1952 1.0 to 1.5 meter. Once an appreciable snow cover has been established, even sub-normal temperatures are not able to impede the gliding, as was the case in the winter of 1966/67.

In the last 60 years there were 12 winters with early and heavy snowfalls. Of these, five were distinct "glide winters", and there was at least one every 15 years. The winter of 1965/66 was the most extreme since the year 1900, so the probability is great that another like it will not occur again soon.

Methods of Investigation, Research Results and Practical Applications

As a rule the measurement sites were so chosen that gliding normally would be encountered. In addition to weather and orographic conditions, the character of the ground surface played an important role. Poorly drained slopes with a dense cover of long grass, and slaty or slabbed rock surfaces, lead to the most vigorous gliding. Our investigations were concentrated at relatively low-elevation locations in the northerly fore-Alps. In higher regions of the inner Alps where snow is scarce, gliding presumably is the exception.

For the most part, glide shoes were used to measure glide in the "Schilt" defenses at Stein and the "Dorfberg" defenses at Davos. This method has been described in (9). It produced about 300 measurements, supplemented by about 80 measurements with saw dust columns in the above-mentioned defenses. The latter method is described in (6). Valuable conclusions about the variations of glide with time were given by the recording measurement system of In der Gand (9). Scattered observations are also available from abroad. In the winter of 1954/55, H. Wopfner conducted glide research on the Wattener Lizum in Tirol, and in the winter 1961/62, H. Frutiger did the same in avalanche release zones of the "Stanley" slide at Berthoud Pass and the "Bethel" slide at Loveland Pass, Colorado, USA.

Earlier authors described the present-day "glide" as "creep". Figure 1 gives the nomenclature for snow cover movement as it is commonly used today.

In the northerly fore-Alps up to around 2400 meters elevation, glide of several decimeters occurs during normal winters on slopes steep enough to require defenses. If weather conditions favor glide, it can reach as much as one or more meters and lead to the release of avalanches running on the ground. For the research slope "Mattstock" at Amden, we have calculated an average velocity of 3.7 mm per day.[1] The average of 290 measurements from the avalanche defense "Schilt" at

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[1]This value refers to the horizontal component of the glide path (horizontal glide path in Figure 1), while all other cited figures refer to the glide path measured parallel to the slope fall line.

Stein and from the research slope "Dorfberg" at Davos gives 3.5 mm per day. Another 63 measurements from other defenses give an average of 5.3 mm per day.[1] Since the snow cover persists from 100 to 200 days in the lower defense sites down to 2000 m, the glide path is 30 to 60 cm long in a normal winter.

The continually recorded glide measurements (9, 10 and 12) show that the gliding is mostly a very uneven motion. Periods of high and low glide velocity alternate with static periods. Within glide periods of a few days to a few weeks the velocity nevertheless remains approximately constant. At "Dorfberg" by Davos it is 1 to 20 cm per day according to varying weather conditions. If weather and snow cover formation favor gliding, velocities of 20 to 100 cm per day can be established. If the snow cover fractures, leading to formation of cracks and pressure folds, maximum velocities up to 4 m per day occur. Reverse motion, whose velocity cannot be determined with the measuring installation, is also observed. This can amount to as much as 10 cm without breaking the snow cover.

If the glide path exceeds about 1 m for the winter in an individual element of terrain, glide cracks are formed at the edges. These are visible expressions of the fact that tensile stress has been relieved in the snow cover. The expression "avalanche mouths" (Lawinenmaeuler) which is sometimes used for these cracks is inappropriate. The presence of the crack indicates that tension has been relieved without forming an avalanche. Reverse glide motion can also indicate equalization of

tension without avalanche release. In most cases the snow cover consolidates once more, with avalanches running on the ground only in favorable terrain. These avalanches are generally less harmful than those which unload the same release zone as dry surface avalanches.

The ability of the snow cover to undergo deformation is surprisingly large. This is illustrated by the considerable differences of glide motion along a profile line without formation of cracks or folds. Relative shearing between adjacent profiles in the order of 1 mm per meter per day has often been observed. The shear stress operating downhill and parallel to the slope, and the vertical settlement, are caused by the weight of the snow. These deformations cause an originally vertical column in the snow cover to be shortened, tilted downhill, and bent into a curve (the latter as a result of the ever-present, inhomogeneous snow accumulation). These deformations are called creep, and the axis of the deformed column the creep profile. We have sought to arrange the different creep profiles in three classes. We began with the theoretical treatments of Haefeli (6, 11) and Bucher (13) which in one case assumed a triangular form and in the other a parabolic form of the creep profile for their snow pressure calculations. In the case of the triangular profile the column remains straight. The parabolic profile we have designated as convex (bulging downhill). We have observed the concave profile as the third type. Allowing for uncertainty of classification, there were 123 (100%) investigated profiles, of which 77(63%) were concave, 32 (26%) straight, and 14 (11%) convex. In two cases at the inner edge of earthen terraces the profiles were found to be bowed uphill. Columns were frequently observed - this was

often the case with heavy gliding - which remained vertical, while other columns on horizontal ground (terraces) were tipped downhill. Surfaces of discontinuity within the snow cover were never observed to conform to column deformation.

As one began to measure the glide motion of the snow cover within the defense structures "Schilt" (Stein) on an east slope at 1400-1550 m above sea level, it was possible readily to detect a partially favorable influence of the retention structures and glide anchors (path terraces, stakes, small structures). Nevertheless, doubts soon arose about the adequacy of their effects. We repeat here some commentaries from the Winter Reports which presented results of the measurements.

The winter of 1950/51 brought very deep snow. In the four previous winters, the measurement sites were largely or completely outside the defended area. "......in 1950/51 <u>all of the measurements sites lay within the defense structure area</u>, which led to the expectation of reduced glide motion. The deep snow, the relatively high temperature and the persistently unfrozen ground all led to the opposite effect. Striking among the research results is the obviously small damming effect of the rakes on the snow cover lying above them. The lowermost glide shoes, which were installed about 3 m above Rakes 33 and 20, still moved downhill 40 to 50 cm. This was at least half of the glide shoe motion farther uphill in the so-called neutral zone. Observations in earlier winters indicated a stronger braking action exerted by the structures on snow glide." The average glide path of the 18 metal shoes

was 56 cm, in contrast to only 11 to 44 cm in the four previous winters.

The influence of a field of stakes was investigated in the winter of 1951/52. "Following directions of the Federal Institute for Snow and Avalanche Research, the stake field consisted of an array of 100 stout posts 60 to 80 cm long, spaced 1 to 1.5 m apart and driven perpendicularly into the ground to at least half their length. The glide distance from 4 December 1951 until melting out of the glide shoes at the beginning of May varied from 10 to 70 cm. The average was 32 cm, and thus smaller than in the previous two winters when it was respectively 44 and 56 cm per shoe. The stake field reduced the glide motion, which was 25 cm within the field but 37 cm outside it. The results of planting the stakes turned out to be rather modest in the light of the considerable expense. Snow glide along the ground can only be reduced, but not prevented. Some stakes were tipped over, which can tear up the soil and damage plants. The damming action of Rake 25 on the glide shoe 4 m above the defense structure could not be detected. Earlier observations were thus confirmed. The influence of defense structures on the plastic deformation of snow appears to be very limited."

"The winter of 1952/53 brought to the vicinity of the Schiltlaui quantities of snow not previously seen. By the middle of November 70 cm of snow were recorded, an unusual amount for this time." The influence of two isolated, square-patterned snow nets of 1.5 by 2.0 m was studied. At the first net no effect could be noticed with relatively small glide motion. "System II showed positive results. While the metal shoes installed 4.7 m above the net glided from 80 to 135 cm

between 12 December 1952 and 5 May 1963, these glide paths were reduced to 50 to 81 cm at a distance of 1.7 m above the net."

The influence of small structures as glide inhibitors was also investigated. In the winter of 1955/56 the measurements lasted from 11 January to 18 May. The zone of influence of a light-metal snow rake 2.5 cm long and 1.8 m high extended over an area of about 60 m^2, with glide paths of 10 to 30 cm. Outside this zone of influence, glide paths of 20 to 60 cm were measured.

"On 14 January 1957, 20 light-metal glide shoes were installed in a 1-meter snow cover on the steep slope adjacent to Snow Rake 27. By the time these research markers were dug out on 27 March, they had covered glide distances of 2 to 38 cm. Considering the high density of wood and light-metal snow rakes, and nets, on this study area, and the relatively low snow depth, the gliding must be described as rather strong. Both the wetting through of the snow cover and the short-grass ground cover must have contributed to the motion. Because the damming effect of the structures is not known, we must conclude that this is relatively moderate. The glide shoes with path lengths of 6, 3, 5 and 9 cm were lightly lodged against obstacles, so the measured values must have been too small. With the determination of an appropriate, readily-measured, but limited effect of supporting structures on snow gliding, earlier observations are confirmed."

In the winter of 1957/58, the glide research lasted from 12 November to 13 May. The displacement of the 24 glide shoes ranged from 17 to 95 cm, with an average of 57 cm. "The glide path below the snow

rakes was somewhat larger than above, but 3.6 m above Rake 33 it was still 40 to 60 cm. This can be attributed to the limited damming effects of the defenses and the very high plasticity of the snow cover." "On 21 November 1958, 25 light-metal glide shoes were installed in a thin snow cover in the vicinity of Snow Net No. 303 (single snow net 2x2 m). The objective was to test the influence zone of the defense structure. The experiment was terminated 23 April 1959 with a wet, cohesionless snow layer. The research results were disappointing insofar as that practically no damming effect of the structure on the snow cover could be detected. In the course of five months the glide paths ranged from 0 to 135 cm, with an average of 66 cm. We consider this to be very high for a defended zone. The glide distance of a metal shoe was governed, not by its position in respect to the supporting structure, but by the ground conditions and the slope angle." In the winter of 1959/60, the damming effect of a single, isolated snow net (No. 87, 2x2 m) was imperceptible.

The influence of supporting structures on gliding was also investigated in other defense systems. Even at 3 m above the supporting members, glide paths of 10 cm or more were commonly measured. In the winters of 1959/60, 1960/61 and 1962/63, an average of 28 cm was measured at five sites in the defense systems "Mattstock" at Amden, "Kunihorn" at St. Antoenien and "Kneugrat" at Braunwald. A longer glide path of 60 cm was found only 3.4 m behind the VOBAG Snow Bridge No. 23/3 at Kunihorn. During glide winters, the uphill effect of supporting structures is minimal around 3 m and practically disappears 4 m away.

The observations in influence of earth terraces on gliding, stretching over five winters, have also produced discouraging results. In two winters, glide paths of around 10 cm were measured on 3-meter wide terraces at Mattstock. The snow cover was pushed over the terraces in a body.

These facts show that glide protection for afforestation and the supporting structures themselves is far from being solved. Our measurements and observations, especially regarding the damage to supporting structures and afforestation by gliding snow, demonstrate the weakness of current preventive measures. The practical man will ask himself the question: Can the expected glide motion, including that in the zone of influence of defense structures, be tolerated for afforestation? An answer was reached in the winter of 1965/66: For many afforestation projects, it unfortunately was in the sense that the setbacks cancelled a year's gain.

Within afforestation zones where the trees do not yet extend above the maximum snow depth, or at most do so occasionally, a significant suppression of snow gliding has been observed. In extreme winters this braking action is achieved by the trees at the cost of self-destruction. We have to admit that chance plays a critical role for afforestation of glide-damage locations. If a series of normal or practically harmless winters occurs so the next glide winter finds a strong stand of young trees, then the afforestation can be saved. On the other hand, when adverse circumstances come into play and the fragile young stand of trees encounters one or more glide winters in a row, many a promising

young growth bows to the force of the snow. It requires much time, patience and tireless effort to achieve success at an extreme locality. In such cases one must be satisfied with a step-like and patchy afforestation scheme which requires for each tree that achieves future full growth the support of a number of satellite trees deformed by the snow.

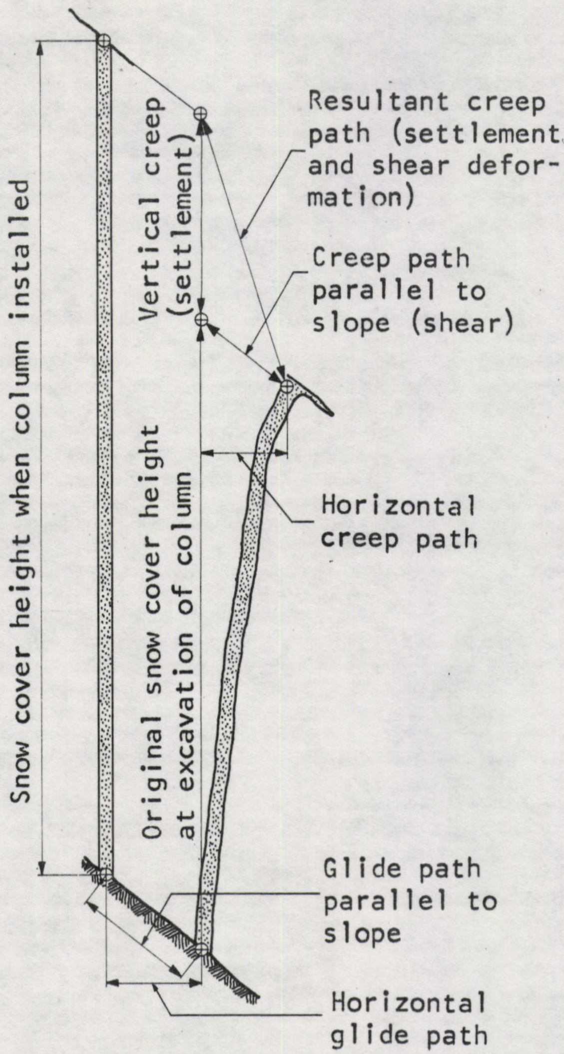

Figure 1   Glide and creep measurements by means of saw dust columns, and scheme of nomenclature

Figure 2   "Mattstock"/Amden.   Shearing and deformation of Sawdust Column No. 3 in the winter of 1964/65. Installed on 24 February, removed on 5 April

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